**VOLATILITY CONTROL OF ISOTOPE HETEROGENEITY IN THE EARLY SOLAR SYSTEM.** T. Yokoyama, Y. Fukami, Y. Nagai, T. Nakamoto  
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**Introduction:** The formation of the solar system has initiated by the collapse of a dense molecular cloud core which was composed of gas and dusts. The dusts in the molecular cloud were originated from diverse stellar environments, thus they had distinctive isotope compositions that were drastically different from each other. It has long been thought that these grains had thoroughly mixed in the molecular cloud and/or in a turbulent protoplanetary disk, resulting in homogeneous stellar environments, thus they had distinctive isotope compositions. The dusts initiating the collapse of a dense molecular cloud had originated from diverse sources in the solar nebula, and decoding how isotopic fractionation and radioactive decay or spallation effects. In order to detect isotope deviations at a level of a few ε or less, we omitted radiogenic isotopes.

**Data Source:** All the data were carefully selected from previous studies published after 2005 in which high precision isotope analyses were performed using new generation mass spectrometers. We compiled isotope compositions for 16 heavy elements from Ti to Os [1-20] in bulk samples of chondrites, achondrites, iron meteorites, and stony-iron meteorites. We specifically focus on isotope compositions of volatile elements, which have not been involved in the discussion for the origin of nebular isotope heterogeneity.

**Results:** Fig. 1 shows ηs values of Te, Ba, Ru, Mo, Sm, Nd, and Os for bulk meteorite samples. We used $^{126}$Te/$^{128}$Te, $^{134}$Ba/$^{136}$Ba, $^{106}$Ru/$^{108}$Ru, $^{97}$Mo/$^{99}$Mo, $^{146}$Sm/$^{150}$Sm, $^{147}$Nd/$^{146}$Nd, and $^{188}$Os/$^{186}$Os ratios for determining ηs values. The most striking feature of this figure is that five out of seven elements show isotope anomalies that exceed the analytical uncertainties of terrestrial samples, which were dominated by the depletion of s-process nuclide (or r-excess) as indicated by the negative ηs values. The exceptions are Os and Te, both of which cannot be resolved from the terrestrial values. Interestingly, Os and Te have the highest and lowest 50% condensation temperatures among seven elements.

Fig. 2 shows ηs values of Te, Ba, Mo, Sm, Nd, and Os for acid leachate and residue samples for chondrites. For Ba, Mo, Sm, and Nd, acid leachates and residues of chondrites possess isotope anomalies much greater than the extent of isotope anomalies observed in bulk chondrites. Though not displayed in Figs. 1 and 2, Cr and Sr are elements where isotope anomalies were observed both in bulk meteorites and more significantly in acid leachates.

**S-process enrichment factor:** To evaluate the inter-elemental relationship regarding the extent of nucleosynthetic isotope anomalies in meteorites, we calculated the s-process enrichment factor ηs (ppm) defined as follows;

$$
\left( \frac{^M_i}{^M_j} \right)_m = \left( \frac{^M_i}{^M_j} \right)_t + 10^{-6} \eta_s \left( \frac{^M_i}{^M_j} \right)_s
$$

where $[^M_i]$ and $[^M_j]$ are the number of atoms for isotopes $^M_i$ and $^M_j$, and subscripts $t$, $s$, and $r$ represent meteorite, terrestrial, and s-process end-component, respectively. The isotope ratios reported in literatures are usually corrected for mass fractionation during analysis by fixing the ratio of two stable isotopes ($^M_i$/$^M_j$). This can be re-corrected as follows;

$$
\left( \frac{^M_i}{^M_j} \right)_m^{rep} = \left( \frac{^M_i}{^M_j} \right)_m \left( \frac{^k_i}{^k_j} \right)_m \left( \frac{w_i}{w_j} \right)_{M/M_k}
$$

where rep means the reported value and $w$ is the isotopic weight. The ηs was calculated by iteratively solving two equations.
Unlike bulk meteorites, the $\eta_s$ values for Os are resolvable from the terrestrial. This implies the existence of isotopically anomalous components within chondrites, although the summation of Os in all chondritic components gives an Os isotope composition identical with that of terrestrial and differentiated meteorites. Such characteristics are also observed for Zr, Hf and W.

On the other hand, Te isotopes are homogeneously distributed at the bulk meteorite scale as well as acid leachates and residues. Though acid leaching data are not available, we note that Zn and Cd isotope compositions in bulk meteorites were not resolvable from the terrestrial.

Over all, we categorized elements into three groups following the characteristics of isotope anomalies of bulk meteorites and acid leachates/residues.

Group 1) Isotope anomalies are observed both in bulk meteorites and in chondrite components.

Group 2) Isotope anomalies are observed in chondrite components but not in bulk meteorites.

Group 3) Isotope anomalies are not observed both in bulk meteorites and in chondrite components.

In the following section, we discuss the possible mechanisms that created observed isotope signatures recorded in meteorites and their components.

**Discussion:** It has been proposed that selective destruction of thermally labile presolar grains in an initially homogeneous solar nebula caused volatility-controlled elemental fractionation in the inner solar system, resulting in radial isotope heterogeneities. To explain the correlation of Ti isotope compositions in bulk meteorites, Trinquier et al. [14] argued that nebular dusts have been heated at different temperatures depending on the heliocentric distance, resulting in partial vaporization of Ti from thermally labile presolar dust grains in different proportions. Likewise, Burkhardt et al. [3] proposed that this mechanism has produced the correlation of Mo and W isotope anomalies among bulk meteorites and chondritic acid leachates. They explained that such thermal processing led preferential loss of Mo but W because of Mo becomes volatile in oxidized conditions while W remains refractory. Therefore, Mo isotope anomalies in bulk meteorites are much pronounced compared to the case of W.

This scenario is attractive because the other refractory elements such as Os, Zr, and Hf show planetary scale isotope homogeneity as well as W. Thus, the difference between group 1 and group 2 elements corresponds to the difference of their 50% condensation temperatures. However, this model is difficult to reconcile with the observation of homogeneous isotope distribution of Te, Zn and Cd, all of which are categorized as moderately volatile elements because of their relatively low 50% condensation temperatures. We predict that these elements would be all categorized into group 3 in which no isotope anomalies are observed both in bulk meteorites and in chondritic components. A likely scenario is, therefore, these elements were completely removed from the host presolar minerals during the thermal processing at the inner part of the solar system, followed by a thorough mixing of these elements as gaseous phases before recondensation.

**References:**